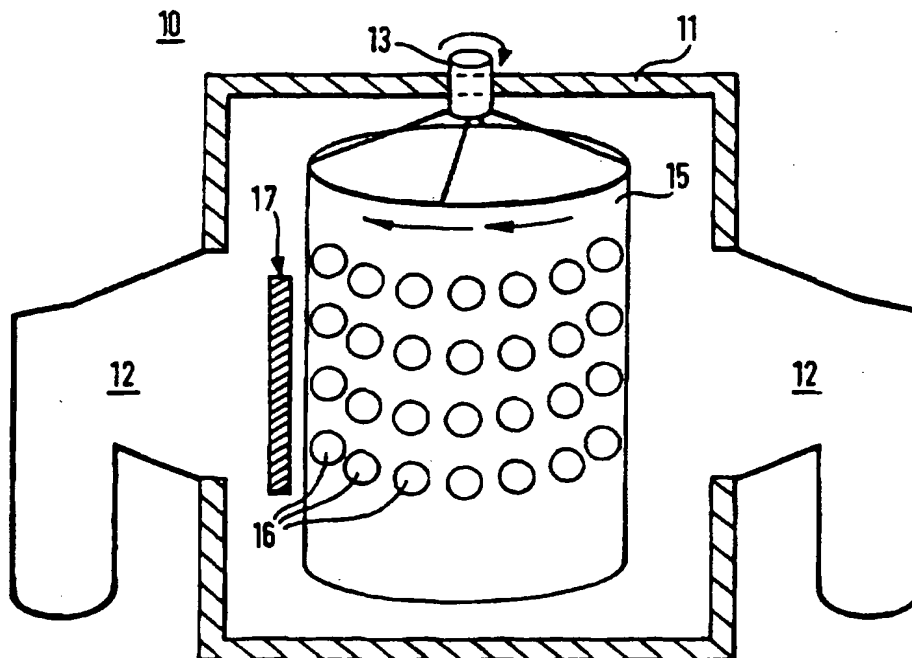




## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<b>(51) International Patent Classification <sup>6</sup> :</b> <b>H01J 37/32, 37/30, C23C 14/00</b>	<b>A1</b>	<b>(11) International Publication Number:</b> <b>WO 96/26532</b>  <b>(43) International Publication Date:</b> 29 August 1996 (29.08.96)
<b>(21) International Application Number:</b> PCT/GB96/00390 <b>(22) International Filing Date:</b> 20 February 1996 (20.02.96)  <b>(30) Priority Data:</b> 9503304.9                      20 February 1995 (20.02.95)      GB  <b>(71) Applicant (for all designated States except US):</b> AVIMO GROUP LIMITED [SG/SG]; 14 Fifth Lok Yang Road, Jurong Town, Singapore 2262 (SG).  <b>(72) Inventors; and</b> <b>(75) Inventors/Applicants (for US only):</b> SHI, Xu [SG/SG]; BLK 356, 5 Woodland Avenue #02-402, Singapore 730356 (SG). FULTON, Michael [US/SG]; 175 Jalan Loyang Besar, Singapore 509428 (SG). FLYNN, David, Ian [GB/SG]; BLK 726, Geh Poh Ville #08-244, Singapore 640726 (SG). TAY, Beng, Kang [SG/SG]; 18 Sin Ming Walk #06-01, Singapore 575569 (SG). TAN, Hong, Siang [SG/MY]; 24 Jalan 17/1, 46400 Petaling Jaya, Selangor (MY).  <b>(74) Agent:</b> SCHLICH, George, William; Mathys & Squire, 100 Gray's Inn Road, London WC1X 8AL (GB).		<b>(81) Designated States:</b> AU, CA, SG, US, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  <b>Published</b> <i>With international search report.</i> <i>Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>

(54) Title: DEPOSITION APPARATUS



## (57) Abstract

Deposition apparatus incorporating either a single or multiple filtered cathodic arc (FCA) source for depositing coatings such as tetrahedral amorphous carbon (TAC); metal oxides; compounds and alloys of such materials onto various types of substrates, such as metal semiconductors, plastic ceramics and glasses. Substrates are moved through the plasma beam(s) of the FCA source(s) and beam scanning increases deposition area. Macroparticles are filtered by a double bend filter duct.

**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AM	Armenia	GB	United Kingdom	MW	Malawi
AT	Austria	GE	Georgia	MX	Mexico
AU	Australia	GN	Guinea	NE	Niger
BB	Barbados	GR	Greece	NL	Netherlands
BE	Belgium	HU	Hungary	NO	Norway
BF	Burkina Faso	IE	Ireland	NZ	New Zealand
BG	Bulgaria	IT	Italy	PL	Poland
BJ	Benin	JP	Japan	PT	Portugal
BR	Brazil	KE	Kenya	RO	Romania
BY	Belarus	KG	Kyrgyzstan	RU	Russian Federation
CA	Canada	KP	Democratic People's Republic of Korea	SD	Sudan
CF	Central African Republic	KR	Republic of Korea	SE	Sweden
CG	Congo	KZ	Kazakhstan	SG	Singapore
CH	Switzerland	LI	Liechtenstein	SI	Slovenia
CI	Côte d'Ivoire	LK	Sri Lanka	SK	Slovakia
CM	Cameroon	LR	Liberia	SN	Senegal
CN	China	LT	Lithuania	SZ	Swaziland
CS	Czechoslovakia	LU	Luxembourg	TD	Chad
CZ	Czech Republic	LV	Latvia	TG	Togo
DE	Germany	MC	Monaco	TJ	Tajikistan
DK	Denmark	MD	Republic of Moldova	TT	Trinidad and Tobago
EE	Estonia	MG	Madagascar	UA	Ukraine
ES	Spain	ML	Mali	UG	Uganda
FI	Finland	MN	Mongolia	US	United States of America
FR	France	MR	Mauritania	UZ	Uzbekistan
GA	Gabon			VN	Viet Nam

## DEPOSITION APPARATUS

The present invention relates to deposition apparatus. Specifically, the invention relates to apparatus and processes for deposition of optical quality coatings such as: tetrahedral amorphous carbon (TAC); metal oxides, nitrides, hydrides, carbon-containing compounds; and other compounds and alloys of metals.

Various methods are known in the prior art for depositing thin-films on substrates. In the field of physical vapour deposition, with which the invention is concerned, these methods include various sputtering techniques such as RF or magnetron sputtering, and the use of filtered cathodic arc sources of positive ions.

US-A-4851095 describes apparatus and process for magnetron sputtering to obtain thin coatings on a range of substrates. Magnetron sputtering can produce a broad beam of coating particles and is thus a suitable technique for the coating of large substrate areas. To date, the films produced by magnetron sputtering are not of sufficient quality in terms of hardness, uniformity and smoothness to be suitable for commercial production of coatings for optical equipment. US-A-4851095 also describes a coating chamber that incorporates a rotatable drum on which is mounted substrates to be coated.

Deposition of coatings using a filtered cathodic arc source is also known in the art, and reviewed by P.J. Martin in Surface Engineering, Volume 9, (1993) no. 1, pages 51-57.

Filtered cathodic arcs known in the art are typically used for short periods of time, or in pulsed and non-continuous mode for coating individual substrates one at time. The problems associated with commercial use of this technology have not been solved. Further, known filtered cathodic arc sources typically produce a plasma beam no more than 3cm in diameter. This is not a suitable size for coating large substrate areas.

Neither known physical vapour deposition or chemical vapour deposition techniques have previously been considered suitable for use on a commercial scale.

There has thus been appreciated the need to be able to deposit high quality thin films on substrates in a commercial process using apparatus that can be used continuously for relatively long periods of time.

It is an object of the invention to provide deposition apparatus for commercial deposition of high quality thin films onto substrates. It is another object of the invention to provide deposition apparatus for deposition of high quality thin films onto large substrate areas. A further object of the invention is to provide deposition apparatus for applying multi-layer coatings onto substrates.

These objects are achieved at least in part by the combination of a coating chamber and a filtered cathodic arc source.

According to the invention there is provided apparatus for applying a coating of positive ions to a substrate comprising:-

- a vacuum chamber,
- a filtered cathodic arc source providing a plasma beam containing the positive ions,
- a substrate to be coated, and
- a substrate holder,

wherein the substrate holder is adapted to move the substrate across the beam of positive ions thereby to coat the substrate with the positive ions.

- 3 -

In an embodiment of the invention, the apparatus comprises magnetic means for scanning the plasma beam over a coating area greater than the area of the plasma beam.

The invention thus enables a large area of substrate to be coated as the substrate is moved through the beam of positive ions generated by the filtered cathodic arc. This enables efficient commercial scale deposition of positive ions onto substrates. By scanning the plasma beam into a coating area of greater size than the area of the plasma beam emitted from the filtered cathodic arc, coating of substrate over an especially large surface area is enabled. Further, the coating beam is necessarily of lower density than the smaller area plasma beam prior to scanning. Therefore, the deposition rate of the scanned beam is lower than the deposition rate of an unscanned beam and deposition on the substrate occurs more slowly. This enables greater control over the depth of deposition on the substrate.

In an embodiment of the invention, the substrate holder is adapted for rotation of the substrate through the plasma beam. In a preferred embodiment, the substrate holder is a rotatable drum and the substrate is mounted on the inner or outer periphery of the drum.

In use of this embodiment immediately above described, one or a plurality of substrates are mounted on the drum periphery and by rotation of the drum while a plasma beam is generated from the filtered cathodic arc a layer of positive ions is deposited onto each substrate in turn as it passes through the plasma beam, which is preferably scanned into a coating beam. The rate of deposition of positive ions onto the substrates is conveniently monitored using techniques known in the art, for example using a crystal rate monitoring system.

In a particular embodiment of the invention the rate of deposition on the substrate is monitored and this deposition information is fed back into the magnetic beam scanning apparatus so as to control the rate of deposition on any particular area of the substrate.

- 4 -

In a further embodiment of the invention, scanning of the plasma beam occurs downstream of filtering of the plasma beam by the filtered cathodic arc source. In another embodiment of the invention the magnetic scanning means scans the plasma beam in a raster scan. The width of the raster is preferably at least 10cm wide, more preferably at least 20cm wide and most preferably at least 30cm wide.

The apparatus of the invention uses a filtered cathodic arc source for continuous coating of one or a plurality of substrates with positive ions from a target at the cathode of the cathodic arc source. This is made possible by the filtered cathodic arc source being suitable for continuous use without overheating. This can be achieved by the provision of a water-cooled anode and a water-cooled cathode in the filtered cathodic arc source, making the source suitable for continuous or long term use. Typically, for a filtered cathodic arc source, continuous use means use for a period of at least 3 minutes, but can also mean use until the target, located at the cathode and from which the positive ions in the coating beam are generated, is substantially consumed. As will be appreciated by a person of skill in the art, complete consumption of the target material is rare as contamination of the plasma beam by ions generated from the cathode material is preferably to be avoided; in practice the target is generally not allowed to be consumed beyond a point at which there is a risk of contaminating the plasma by arcing directly between cathode and anode.

A particularly preferred filtered cathodic arc source for use in the apparatus of the invention is described and claimed in a co-pending International patent application filed in the name of Avimo Singapore Limited on the same day as the present application, the content of which is incorporated herein by reference.

In a particularly preferred embodiment of the invention suitable for applying multi-layer coatings of positive ions to a substrate, the apparatus further comprises at least a second filtered cathodic arc source providing a plasma beam containing positive ions, and a substrate holder adapted to move the substrate across the beams from the respective filtered cathodic arc sources.

- 5 -

In use of an embodiment of the invention, a first filtered cathodic arc source is used to place a first coating layer on a substrate; subsequently, this first cathodic arc source is stopped and a second cathodic arc source is used to place a second layer of a different material onto the substrate. This technique is advantageously used to deposit multi-layer coatings onto optical elements. A multi-layer coating made using the invention comprises a first layer of tetrahedral amorphous carbon, a second layer of silicon dioxide, a third layer of tetrahedral amorphous carbon and a fourth layer of silicon dioxide. Another optical coating obtainable using the apparatus of the invention has a first layer of aluminum oxide, a second layer of tetrahedral amorphous carbon and a third layer of silicon dioxide. Other combinations of coatings in multi-layer coatings will be apparent to the practitioner.

Multi-layer coatings are also achieved in another embodiment of the invention in which deposition apparatus comprises a filtered cathodic arc source and the source has at least two cathode targets, one in a vacuum chamber at a cathode station from which an arc can be generated and the other or others stored away from the cathode station. The cathode targets are interchangeable without breaking vacuum in the chamber. Means for interchanging the cathode targets conveniently comprises a cathode gripper mounted on an arm and moveable between the cathode station and the stored cathode target or targets, which may be in a cathode magazine.

Scanning of the plasma beam can be achieved by scanning techniques known and appreciated in the art. For example, a magnetic scanner using a soft magnetic core can be used with a scanning frequency of 2-100 Hz.

In a particular embodiment of the invention, the plasma beam is scanned in two dimensions using magnetic fields scanned perpendicular to each other. This scanning technique produces a coating beam that is two dimensional in area and can be used in the coating apparatus of the invention. By monitoring the rate of deposition on the substrate and actively feeding back this deposition rate information to the scanning apparatus coatings of excellent uniformity are

- 6 -

achieved. An embodiment of the invention uses electronic scanning control means. This control means is pre-programmed with a pre-determined rate of deposition for separate areas of the substrate. The rate of deposition in each area of the substrate is monitored, this information is fed back to the scanning control means and the scanning is adjusted so as to obtain the desired rate of deposition in each deposition area.

In embodiments of the invention, when carrying out scanning of the beam in two dimensions, a typical arrangement is a scanning frequency of about 50 Hz in one dimension and about 2 Hz in the other dimension. As will be appreciated by a person of skill in the art, scanning of the beam using frequencies that are chosen so that the frequency in one dimension is significantly different to the frequency in the other dimension gives a paint brush type scanning pattern. When frequencies are chosen so as to be similar in both dimensions, the result is typically a pronounced scanning pattern. Synchronised scanning frequencies in both dimensions produces Lissajou figures.

In typical use of deposition apparatus according to the invention, the plasma beam is scanned rapidly in one dimension only, at a scanning frequency typically of at least 20 Hz, preferably around 40-80 Hz. A convenient frequency is that of mains electricity, namely around 50 Hz. Scanning in one dimension is combined with movement of the substrate across the scanned beam, a substrate being mounted on the periphery of a rotating drum. A typical rotation produces substrate movement in the range of 0.1 m/s to 10 m/s. It is convenient to arrange the scanning frequency so as to be approximately 10 times that of the rotating drum.

It is particularly preferred to scan the plasma beam in one dimension only. This enables the dimensions of the duct containing the scanned plasma beam to be fan-shaped and enables the scanning mechanism to be approached close to the plasma beam inside the plasma duct.



- 7 -

The use of a scanned plasma beam confers considerable advantages over prior art magnetron sputtering devices as these devices generate atoms of coating material which are neutrally charged and cannot be scanned. The scanning mechanism of the preferred embodiment of the invention enables precise user control of the rate of deposition on the substrate as well as precise control over the deposition profile for the surface of a substrate.

In another embodiment of the invention the apparatus comprises means for biasing the substrate to a pre-determined positive potential. Preferably, the substrate is biased to a potential within a certain range, preferably to within 10V-30V. It is preferred to control the positive bias on the substrate to control the energy of positive ions arriving at the substrate and thereby to alter the properties of the deposited layer.

For optical elements and other dielectric substrates, RF means can be used to provide the appropriate biasing.

Using apparatus according to the invention it is possible to deposit high quality films of tetrahedral amorphous carbon from a graphite target. It is known that such high-quality films are typically compressively stressed. In a preferred embodiment of the invention a substrate is coated with both a layer of tetrahedral amorphous carbon that is compressively stressed and also a layer of a coating that is tensile stressed, such as aluminium oxide ( $\text{Al}_2\text{O}_3$ ), zinc sulphide ( $\text{ZnS}_2$ ) or zinc selenide ( $\text{ZnSe}_2$ ).

In a particularly preferred embodiment described in detail below, the invention uses a cylindrical processing configuration in which substrates are mounted on a rotating cylindrical drum carrier. The substrates are moved past a set of processing stations comprising filtered cathode arc (FCA) sources alternately to deposit single thin-film layers of a particular material which culminates in a complete multi-layer thin-film system.

- 8 -

The substrates are optionally electrically biased with a DC or RF system that confers an acceleration potential for the discharged ions emerging from the FCA source. Also, this arrangement is scalable in that a multiple number of FCA sources can be installed to deposit over a larger substrate area. As one example, three FCA sources are arranged to sequentially deposit TAC, Aluminum Oxide, and Silicon Dioxide to form an anti-reflective coating on either plastic or glass substrates. As another example two or more FCA sources are adapted to operate simultaneously with targets of the same material to deposit a coating on a substrate, or plurality of substrates, at increased rate.

Another aspect of the invention provides apparatus for applying a coating of positive ions onto a dielectric substrate, the apparatus comprising:-

means for generating an arc at a cathode target, the cathode target containing the ions to be deposited on the dielectric substrate,

magnetic means for directing a beam of ions emitted from the cathode along a filter path substantially to remove macroparticles therefrom,

means for holding the dielectric substrate in the filtered ion beam, and

means for applying RF bias to the optical element to dissipate electrostatic charge accruing on the element by deposition of positive ions.

The apparatus of the invention, incorporating the FCA deposition sources provides rapid, uniform deposition of optical quality coatings on both flat and curved parts. The efficiency of the FCA deposition system provides high deposition rates coupled with the thermal and deposit spread over a large substrate surface area permitting high rate of thin-film synthesis on plastic and other temperature-sensitive materials.

By adjusting the starting material, deposition rate, reactive gas type, and substrate bias we can deposit films consisting of precise stoichiometry and composition.

- 9 -

A particular aspect of this invention, as compared to other systems, is the ability to deposit tetrahedral amorphous carbon (TAC), or "diamond like carbon" (DLC), on ambient temperature substrates. The quality of this film exceeds other DLC films deposited at elevated temperature in terms of hardness, thermal conductivity, refractive index, and surface smoothness. TAC in combination with other materials provides a unique technology for depositing multi-layer thin-films onto a variety of shapes and temperature-sensitive substrates.

Specific embodiments of the invention combine FCA deposition sources and a rotary cylindrical work-piece support to provide a deposition system which is capable of high rate synthesis of single or multi-layer optical films of materials such as, but not limited to, tetrahedral amorphous carbon (TAC),  $\text{Al}_2\text{O}_3$ ,  $\text{TiO}_2$ ,  $\text{Ta}_2\text{O}_5$ , and  $\text{SiO}_2$ . This combination provides for high rate depositions of optical quality thin-films on temperature-sensitive substrates. The application of a DC or RF bias (for conductive and non-conductive substrates, respectively) is necessary to the deposition of the films. This DC or RF bias is applied to the substrate holder which is electrically isolated from the chamber.

There now follows a description of specific embodiments of the invention in which:-

Figs. 1 and 2 are, respectively, a simplified schematic perspective view and a simplified schematic horizontal sectional view, of a single-rotational cylindrical drum FCA vacuum coating system which embodies the principles of our present invention;

Figs. 3-8 depict calculated the transmission or reflectance curves for a single layer of TAC deposited on a Germanium substrate (Fig. 3), a multi-layer anti-reflection coating on Germanium consisting of TAC and Ge (Fig. 4), a multi-layer anti-reflection coating on either glass or plastic substrates consisting of TAC and  $\text{SiO}_2$  (Fig. 5), a multi-layer, anti-reflection coating on either glass or plastic substrates consisting of TAC,  $\text{Al}_2\text{O}_3$ , and  $\text{SiO}_2$  (Fig. 6), a transmission curve of multi-layer

- 10 -

laser mirror coating consisting of TAC and  $\text{SiO}_2$  (Fig. 7), and a reflection curve of the same multi-layer laser mirror coating consisting of TAC and  $\text{SiO}_2$  (Fig. 8); and

Figs. 9 and 10 are photographs of deposition apparatus according to the invention.

Figs. 1 and 2, respectively, depict a simplified schematic perspective view and a horizontal sectional view of a single rotation embodiment of our FCA vacuum system. The illustrated FCA system (10) comprises a housing (11) which forms a vacuum processing chamber and is connected to a suitable vacuum pumping system (19) shown in Fig. 2. The vacuum pumping system includes a suitable vacuum pump or combinations thereof for exhausting and pumping down the vacuum chamber to a vacuum of at least  $10^{-6}$  Torr and a mechanical pump for vacuum regeneration, as is conventional with vacuum chambers. The chamber is mounted on a frame comprising a rack for instruments and a control panel having electrical connections to sensors in and around the chamber to monitor chamber pressure, arc power supply, drum motor power supply and deposition rate. The system (10) also includes a cage-like drum (15) which is mounted for rotation about shaft (13) and has a cylindrical side which is adapted for mounting substrates (16) of various configurations. The substrates (16) can be mounted directly on the drum (15) facing outwardly toward the FCA sources (12) and the linear ion source (17) which are spaced about the external periphery of the drum (15).

The rotating drum (15) is located within a vacuum chamber that is roughly cylindrical and has a port allowing access to a cylindrical drum mounted within the chamber. The chamber diameter is approximately 24 inches (50cm) and the drum diameter is approximately 15 inches (38cm). The drum is approximately 15 inches (38cm) high.

The drum is rotated via a vacuum rotary feed-through, allowing rotational drive to be imparted to the drum without breaking vacuum in the chamber. An electric motor (not shown) is located on top of the chamber to drive rotation of the drum

- 11 -

via a central shaft attached to the drum and projecting out of the chamber through the vacuum rotary feed-through. The drum is mounted on bearings on the bottom of the chamber.

Three filtered cathode arc sources (12) are attached to the vacuum chamber at distal ends of their respective plasma ducts, these distal ends meeting the vacuum chamber wall at rectangular openings approximately 7 inches wide and 12 inches high (18cm wide and 30cm high). In both cases, the distal plasma ducts of the filtered cathode arc sources are attached to the wall of the chamber such that when no plasma beam scanning is taking place the plasma beam is normal to the chamber wall and normal to the cylindrical drum. The filtered cathode arc sources comprise double bend plasma ducts for filtering macroparticles from the plasma beam. The plasma ducts are approximately 6 inches (15cm) in diameter, increasing at their distal ends to a rectangle of 7 inches wide and 12 inches high (18cm wide and 30cm high) to allow for scanning of the beams.

The cathode arc sources (12) are located, when viewed from above approximately 90 degrees apart and operate independently of each other. Each can provide a deposition rate of 15 angstroms per second over an area of  $25 \text{ in}^2$  ( $157 \text{ cm}^2$ ) at an arc current of 70A.

Each filtered cathode arc source has a water cooled anode and a water cooled cathode, and also water cooling for the coils providing magnetic steering fields for the double bends. Each filtered cathode arc source can operate continuously, i.e. until the cathode target is substantially consumed.

A deposition rate monitor (not shown) is located inside the drum and attached to a central rod inside the drum, and having electrical connections via the vacuum feed-through to the control panel. Apertures in the surface of the cylindrical drum allow ions from the plasma beam to impinge upon the deposition rate monitor and allow accurate monitoring of deposition rate.

- 12 -

The drum is electrically insulated from the chamber and the apparatus allows the operator the option of applying a DC bias or an RF bias to the drum. The apparatus allows a bias of up to 1000 volts to be applied to the drum, applied through the drum shaft.

In use, the filtered cathode arc sources can be used simultaneously to obtain high deposition rates of diamond-like carbon films having low macroparticle counts. While the deposition apparatus of this specific embodiment uses three filtered cathode arc sources, it would be a matter of routine for a person of skill in the art to prepare apparatus having only one, or two or more than two filtered cathode arc sources. Of practical concern, an additional source can be located on the door of the vacuum chamber.

The deposition apparatus of the specific embodiment is also used to deposit multi-layer coatings on to a substrate without breaking vacuum in the vacuum chamber. To obtain such multi-layer coatings, one filtered cathode arc source is operated using a target such as graphite, producing a diamond-like carbon first layer, and the second filtered cathode arc source is not operated during deposition of the first layer but is thereafter operated using a different target, such as silicon with injection of oxygen gas to obtain a silica layer on top of the diamond-like carbon layer. The calculated reflectance of such a multi-layer coating is shown in Fig. 5.

Each filtered cathode arc source has a filter duct between the cathode target and the substrate, and a magnetic steering field provided by coil windings around the duct to steer positive ions through the duct.

The invention is of use in providing the following coatings:

1. Germanium and Silicon for infrared Applications: Rain Erosion Protective Multi-layer Coatings.
2. Zinc Sulphide and Zinc Selenide for Infrared Applications.

- 13 -

3. Glass Eyeglass Lenses.
4. Plastic Eyeglass Lenses.
5. Anti-Reflective Coatings for Plastics.
6. Multi-Layer Designs for a Variety of Substrates.
7. Tool Hardening Applications.
8. Protective Coating for Hard Disk Drives.
9. Medical Applications: Durable, frictionless Artificial Joints.
10. Hard Smooth Coatings for Tape Reading Heads.
11. Car Panels, Windscreens.

Referring to Figs. 9 and 10, deposition apparatus (100) comprises a vacuum chamber (120) and two FCA sources (102, 111). The first source (102) has a cathode and anode (101) for generating an arc from a target (not shown). Positive ions from the target are filtered by a double bend duct comprising a first straight section (103), a first bend (104), a second straight section (105), a second bend (106) and a third straight section (107) that opens into the vacuum coating chamber (120). Both ducts are toroidal in cross-section and have a double bend preventing a line-of-sight from the target to the substrate and preventing also a single bounce path from the target to the substrate. Ports (121) on the chamber allow visual inspection of substrates mounted on a rotatable drum (not shown) inside. Positive ions are steered through the duct by a magnetic field produced from coil windings around the whole length of the duct.

- 14 -

The first bend (104) has an angle of 50 degrees and the second bend (106) has an angle of 60 degrees. These two bends are in different planes, such that the resultant angle between (i) plasma entering the duct and passing through the first straight section (103) and (ii) plasma passing through the third straight section and exiting the duct is 90 degrees.

Likewise, positive ions from the second source are filtered by a double bend duct having first, second and third sections (112, 114, 116) and first and second bends (113, 115). In the case of the second source, the first bend (113) has an angle of 35 degrees, the second bend (115) has an angle of 40 degrees and the resultant angle between the first and third straight sections (112, 116) is 45 degrees.

A frame (122) bears the coating chamber and the two FCA sources. Other aspects of the apparatus as described for Figs. 1 and 2.

Variations and modifications from the described specific embodiments will be apparent from the description to a person of skill in the art and consequently the invention is not to be construed as limited to any specific embodiment.



**CLAIMS**

1. Apparatus for applying a coating of positive ions to a substrate comprising:-  
  
a vacuum chamber,  
  
a filtered cathodic arc source for providing a plasma beam containing the positive ions,  
  
a substrate to be coated, and  
  
a substrate holder,  
  
wherein the substrate holder is adapted to move the substrate across the beam of positive ions thereby to coat the substrate with the positive ions.
2. Apparatus according to Claim 1 comprising magnetic means for scanning the plasma beam over a coating area greater than the area of the plasma beam.
3. Apparatus according to Claim 2 wherein scanning of the plasma beam occurs downstream of beam filtering.
4. Apparatus according to Claim 2 or 3 comprising means for scanning the plasma beam in a raster.
5. Apparatus according to Claim 2, 3 or 4 wherein the beam is scanned to a width of at least 10cm, preferably at least 20cm, most preferably at least 30cm.
6. Apparatus according to any of Claims 1-5 wherein the substrate holder is adapted for rotation of the substrate through the plasma beam.

- 16 -

7. Apparatus according to Claim 6 wherein the substrate holder is a rotatable drum and the substrate is mounted on the inner or outer periphery of the drum.
8. Apparatus according to any of Claims 1-7 for applying multi-layer coatings of positive ions to a substrate, the apparatus further comprising at least a second filtered cathodic arc source providing a plasma beam containing positive ions, and a substrate holder adapted to move the substrate across the beams from the respective filtered cathodic arc sources.
9. Apparatus according to any of Claims 1-8 wherein a filtered cathodic arc source comprises a first cathode located at a cathode station, means for generating an arc at the station, a second cathode and means for interchanging the cathodes without breaking vacuum.
10. Apparatus according to Claim 9 wherein the second cathode is one of a plurality of cathodes stored in a cathode magazine.
11. Apparatus according to any of Claims 1-10 comprising means for applying a DC or RF bias to the substrate.
12. Apparatus according to any preceding claim comprising a filtered cathode arc source comprising a filter duct having two bends.
13. Apparatus according to Claim 12 in which the filter duct has a first bend in a first plane and a second bend in a second plane that is not co-incident with the first plane.
14. Apparatus according to any preceding claim comprising two filtered cathode arc sources having cathode targets of the same material and adapted for simultaneous operation.

- 17 -

15. Apparatus according to any of Claims 1-14 for coating positive ions onto a dielectric optical substrate.
16. Apparatus for applying a coating of positive ions onto a dielectric substrate, the apparatus comprising:-
  - means for generating an arc at a cathode target, the cathode target containing the ions to be deposited on the dielectric substrate,
  - magnetic means for directing a beam of ions emitted from the cathode along a filter path substantially to remove macroparticles therefrom,
  - means for holding the dielectric substrate in the filtered ion beam, and
  - means for applying RF bias to the optical element to dissipate electrostatic charge accruing on the element by deposition of positive ions.
17. Apparatus according to Claim 16 comprising a filter duct having two bends.
18. Apparatus according to Claim 17 wherein each bend is at least 20 degrees and the bends are in non-coincident planes.

FIG. 1

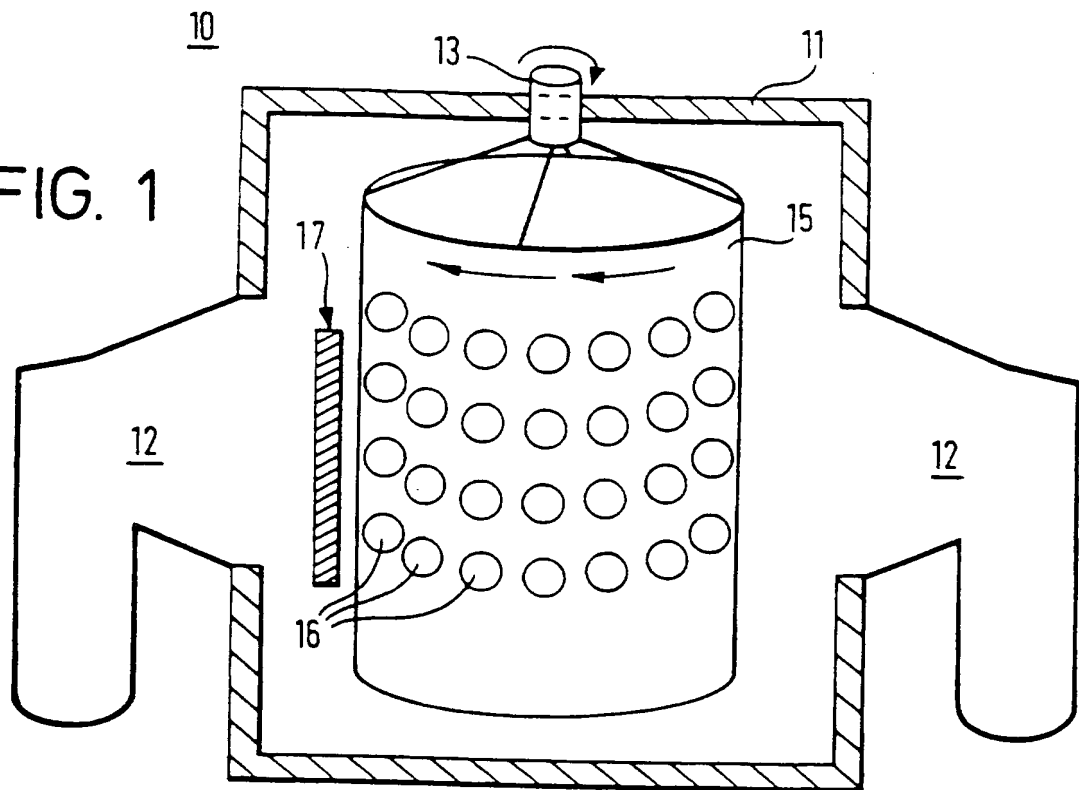


FIG. 2

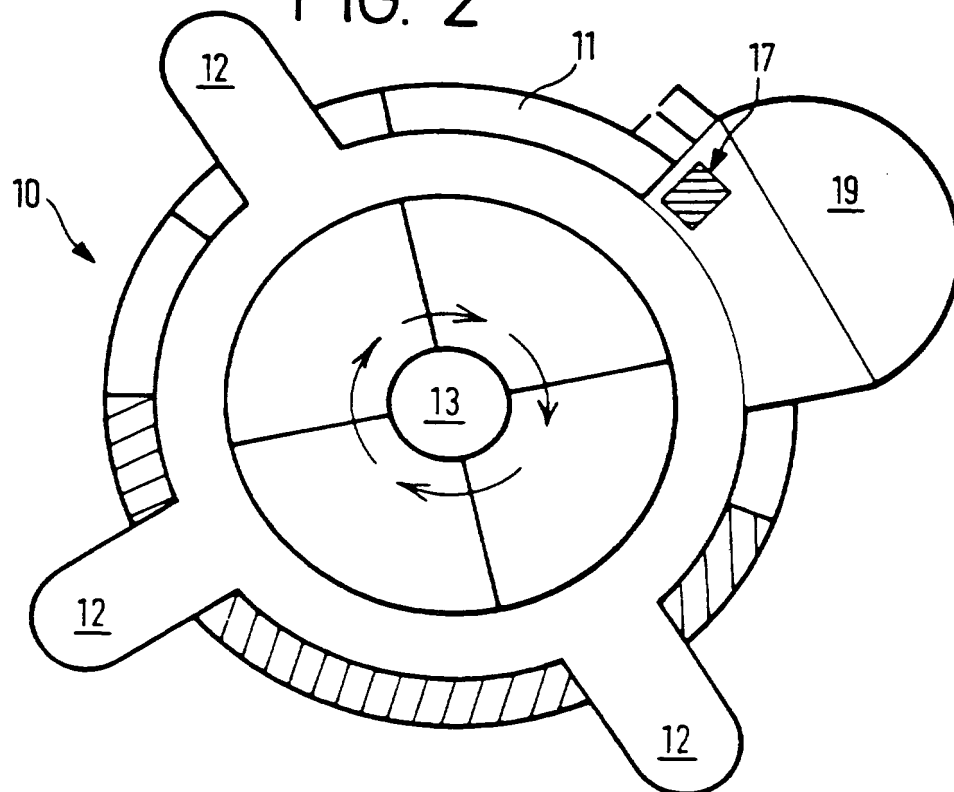


FIG. 3

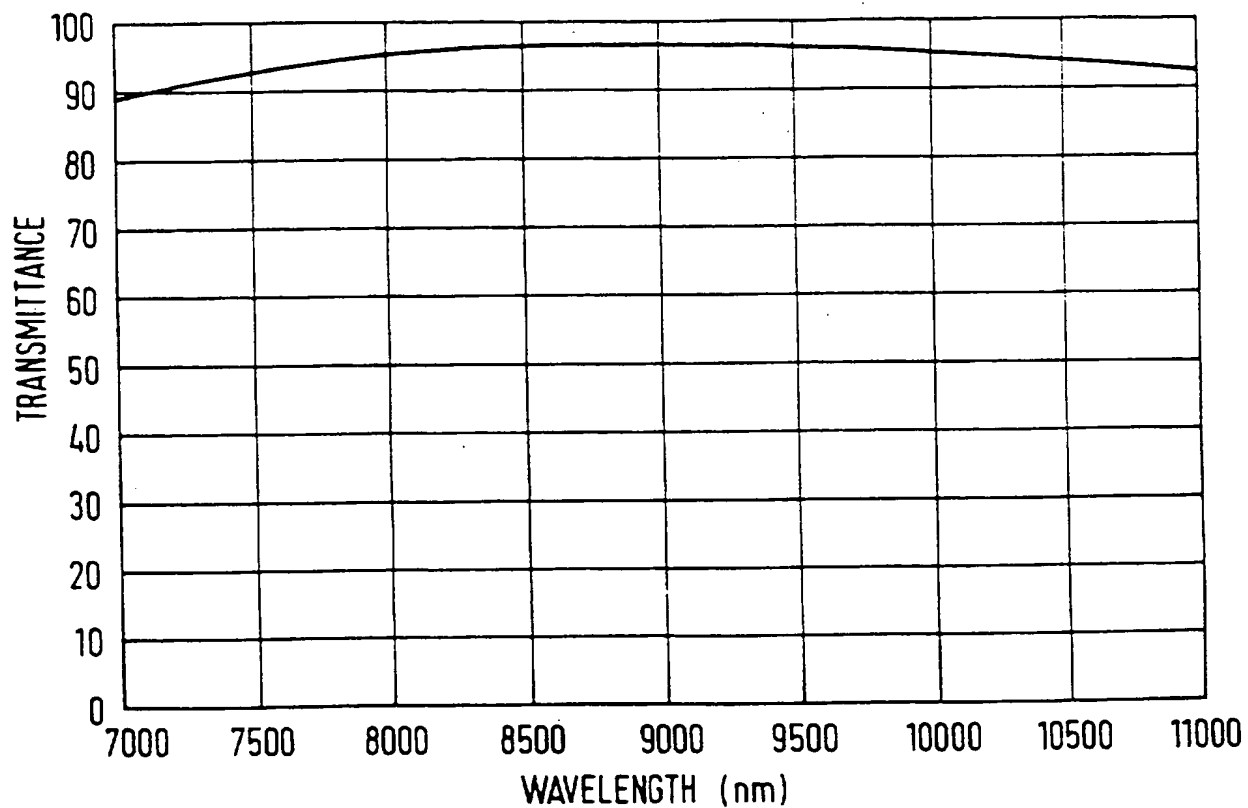


FIG. 4

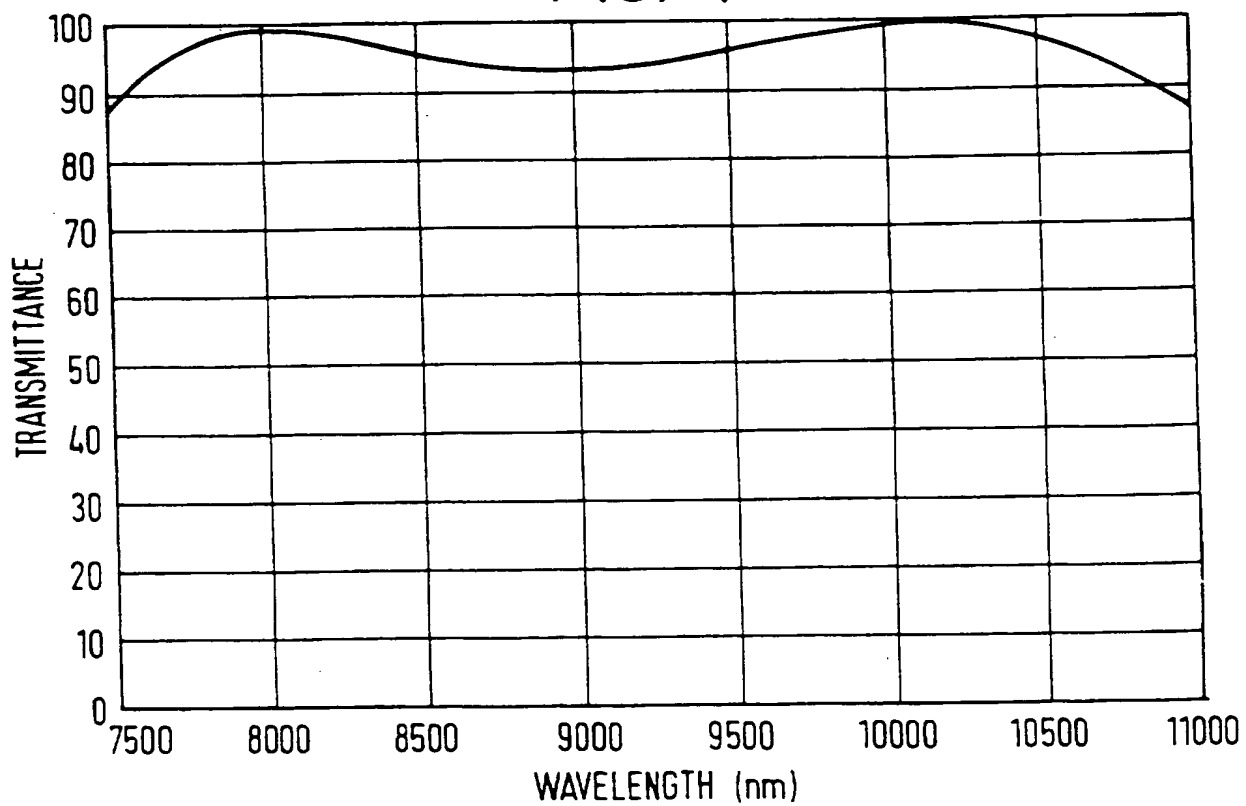


FIG. 5

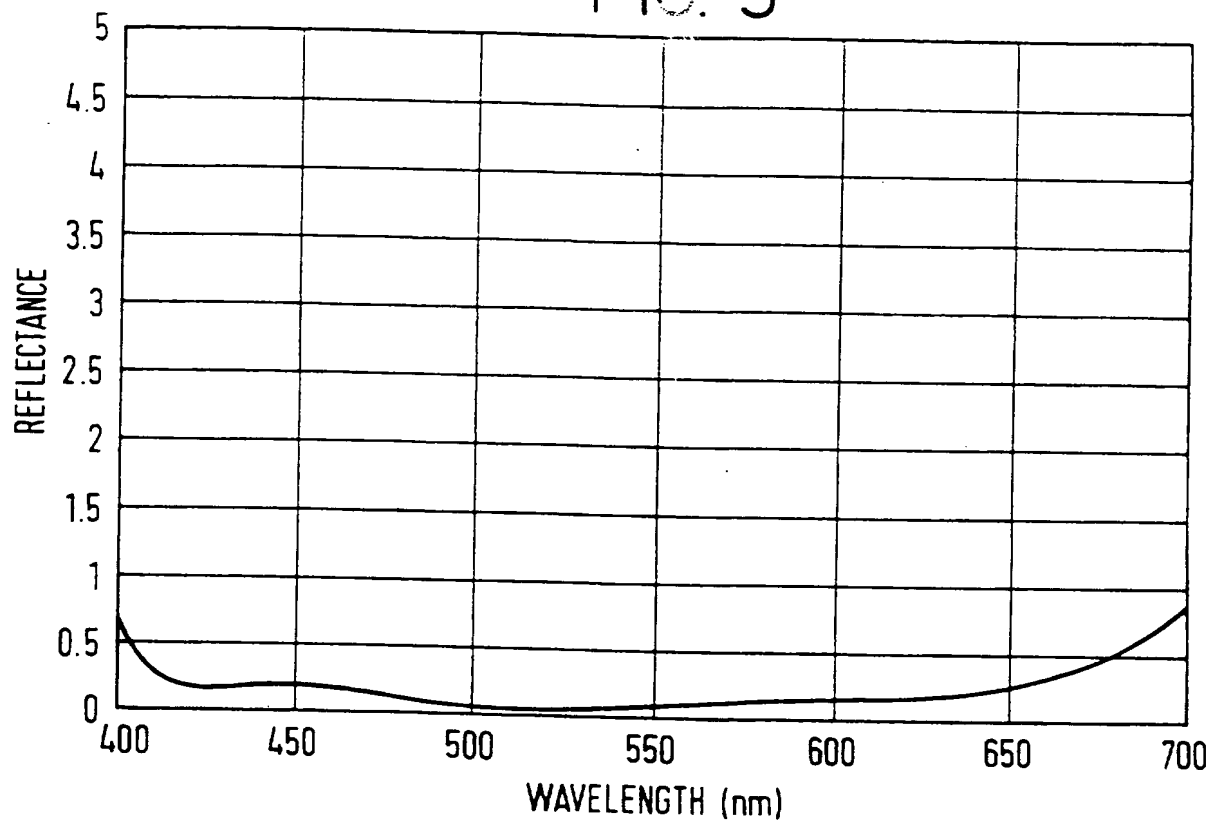


FIG. 6

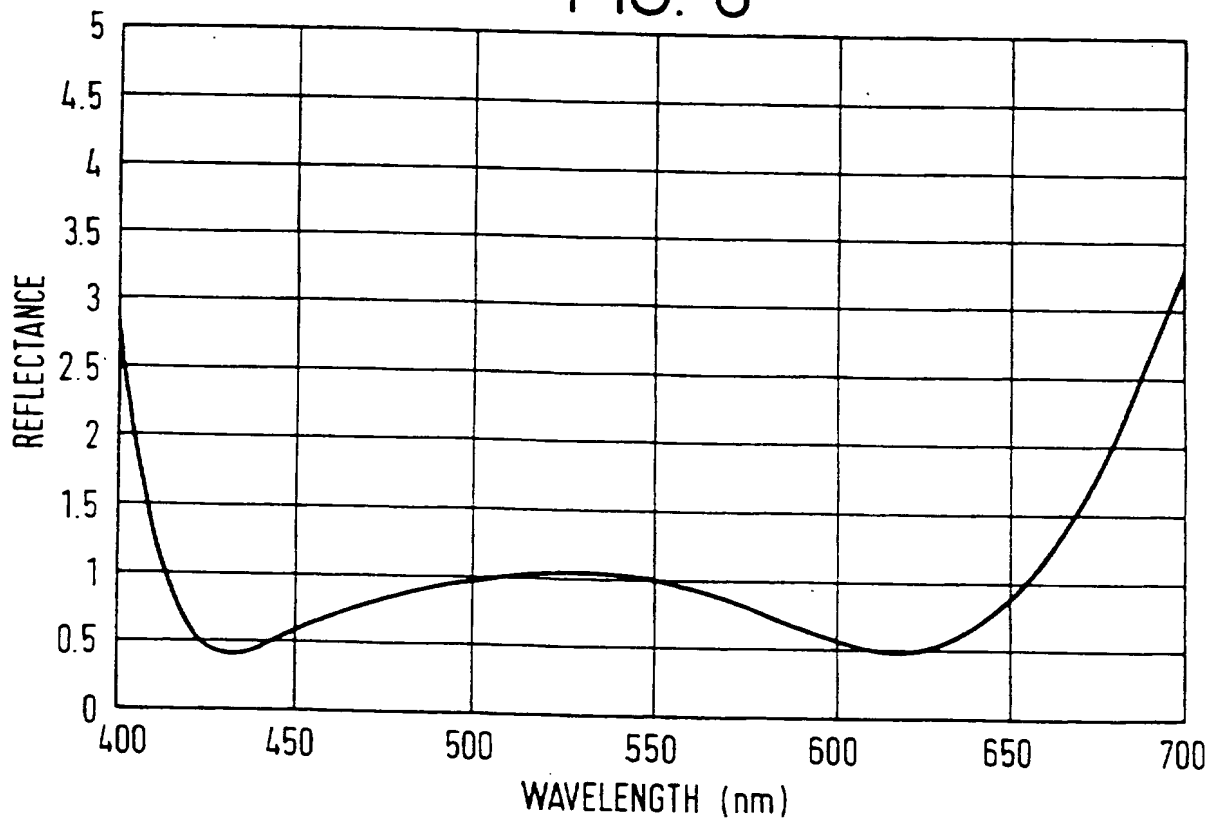


FIG. 7

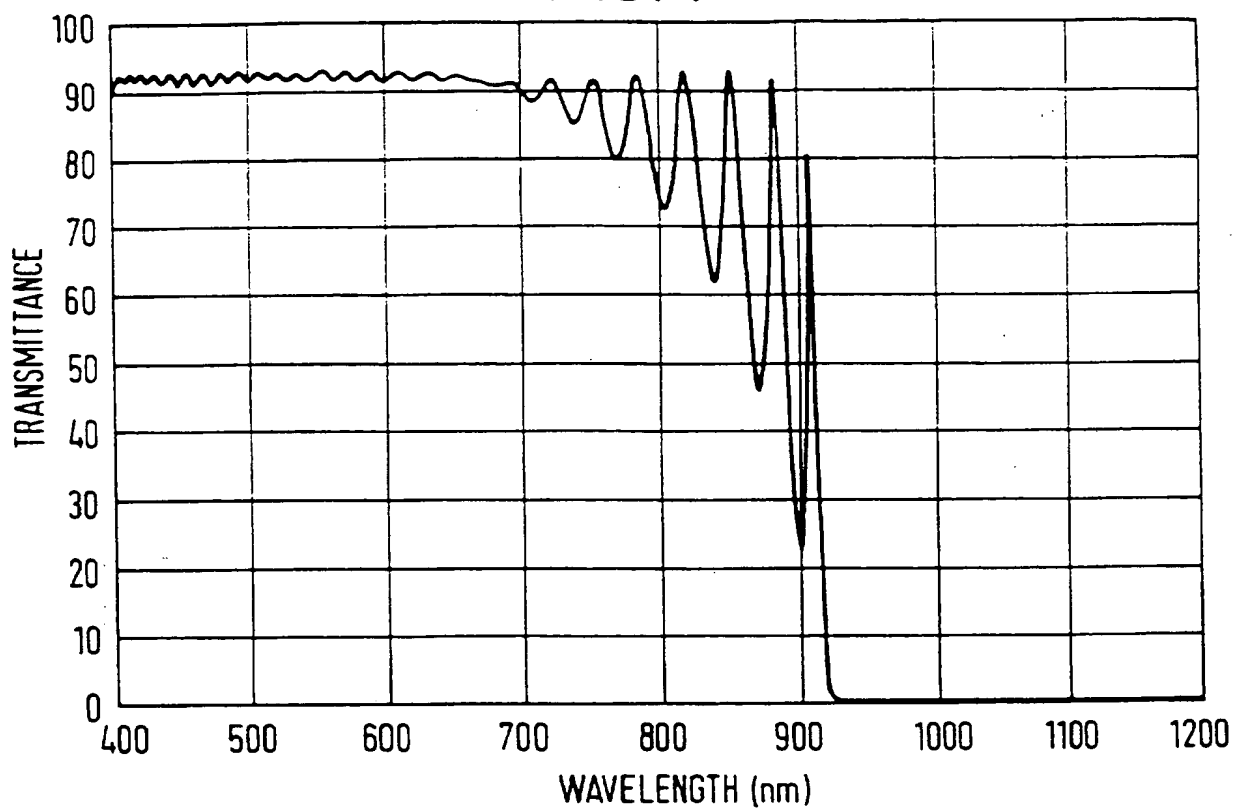
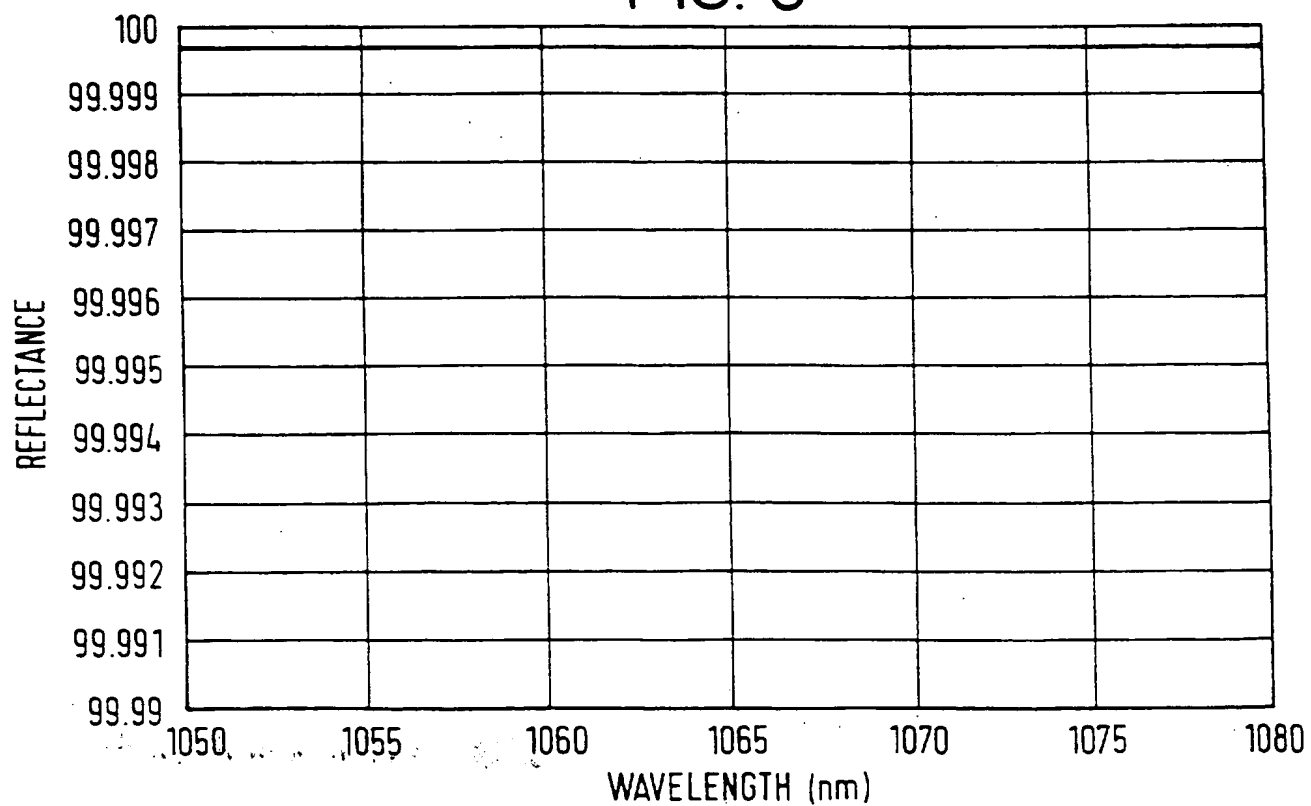


FIG. 8



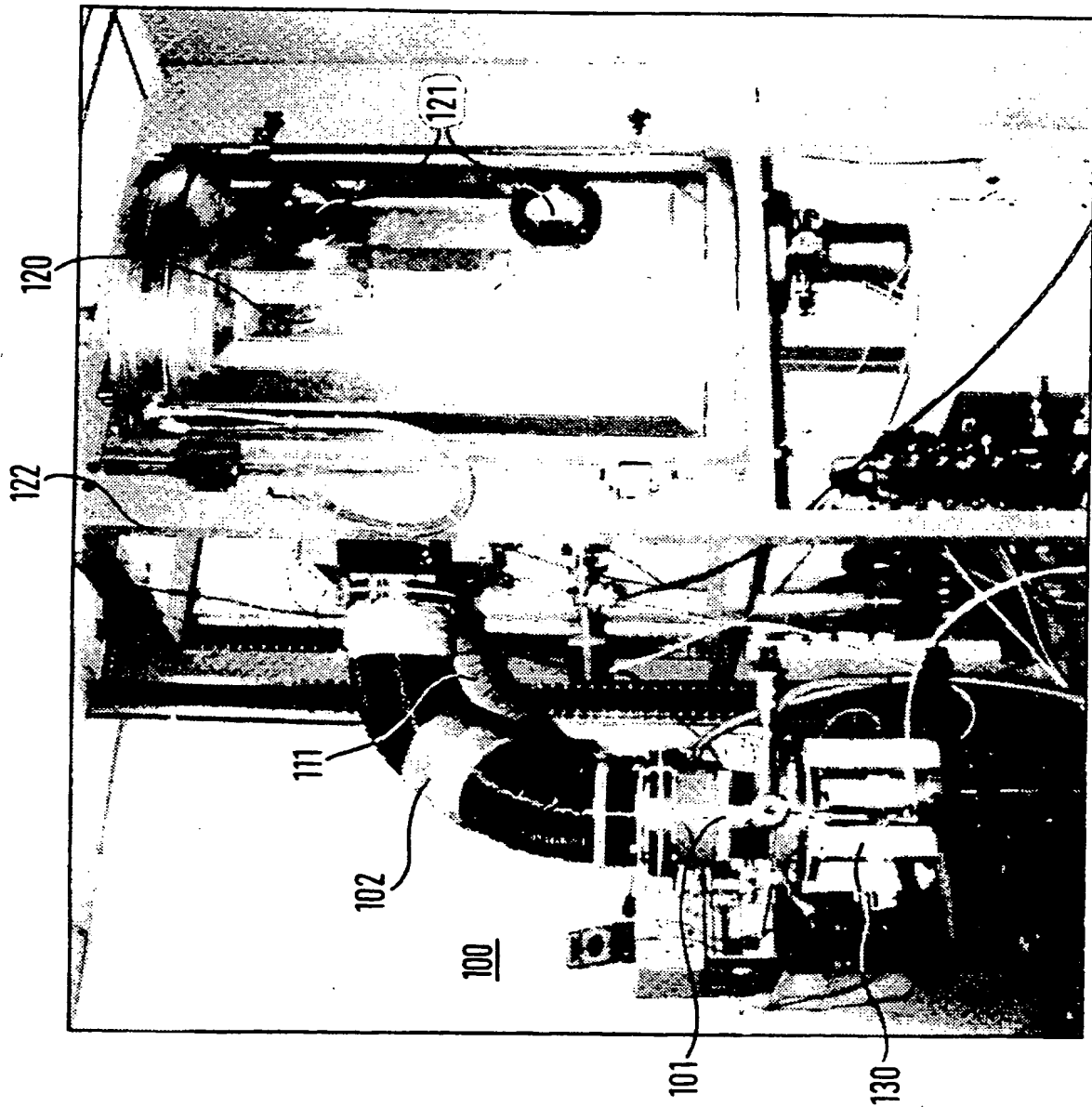
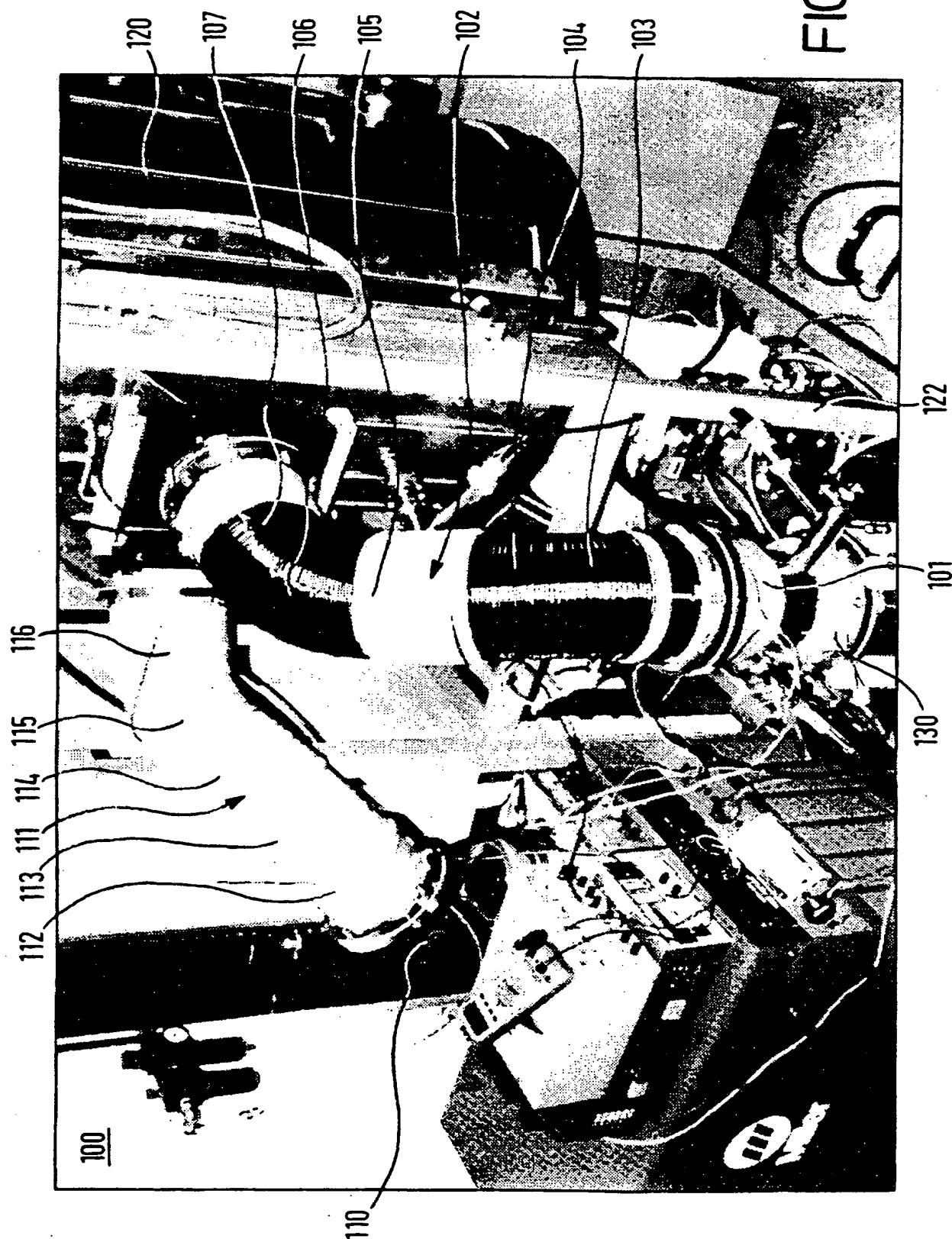


FIG. 9



FIG. 10



**BEST AVAILABLE COPY**

## INTERNATIONAL SEARCH REPORT

International Application No.

PC./GB 96/00390

A. CLASSIFICATION OF SUBJECT MATTER  
 IPC 6 H01J37/32 H01J37/30 C23C14/00

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
 IPC 6 H01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US,A,5 267 289 (BRYAN WILLIAM J) 30 November 1993	1,6,7
A	see column 2, last paragraph - column 3, paragraph 1; figure 1 ---	16
X	DE,A,40 16 087 (HAUZER HOLDING) 21 November 1991 see abstract see column 2, line 8 - line 36; claims 8-10; figure --- -/--	1,6

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

## \* Special categories of cited documents:

- \*A\* document defining the general state of the art which is not considered to be of particular relevance
- \*E\* earlier document but published on or after the international filing date
- \*L\* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- \*O\* document referring to an oral disclosure, use, exhibition or other means
- \*P\* document published prior to the international filing date but later than the priority date claimed

\*T\* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

\*X\* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

\*Y\* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

\*&\* document member of the same patent family

Date of the actual completion of the international search

21 June 1996

Date of mailing of the international search report

28.06.96

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2  
 NL - 2280 HV Rijswijk  
 Tel. (+ 31-70) 340-2040, Tx. 31 651 epo nl,  
 Fax (+ 31-70) 340-3016

Authorized officer

Hulne, S

## INTERNATIONAL SEARCH REPORT

International Application No

PL./GB 96/00390

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A,P	JOURNAL OF VACUUM SCIENCE AND TECHNOLOGY: PART A, vol. 13, no. 4, 1 July 1995, pages 2233-2240, XP000540950 ZHITOMIRSKY V N ET AL: "UNSTABLE ARC OPERATION AND CATHODE SPOT MOTION IN A MAGNETICALLY FILTERED VACUUM-ARC DEPOSITION SYSTEM"	1-4,11
X,P	see page 2234, left-hand column, paragraph 1-3; figure 1	16
A	--- WO,A,92 16959 (COMMW SCIENT IND RES ORG ;SUTTON TOOLS PTY LTD (AU)) 1 October 1992 see abstract see page 6, line 12 - line 17	1-4
A	--- SURFACE ENGINEERING, vol. 9, no. 1, 1 January 1993, pages 51-58, XP000569208 MARTIN P J: "FILTERED ARC EVAPORATION CURRENT STATUS REVIEW" cited in the application see page 53, last paragraph - page 54, left-hand column; figure 5	1,16
A	--- US,A,4 851 095 (SCOBAY MICHAEL A ET AL) 25 July 1989 cited in the application see column 6, last paragraph; figures 1-3	1,6,7
P,X	--- WO,A,95 29272 (VAPOR TECHNOLOGIES INC) 2 November 1995 see page 15, line 3 - line 6; figure 3 -----	1,16

## INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PL./GB 96/00390

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A-5267289	30-11-93	NONE	
DE-A-4016087	21-11-91	NONE	
WO-A-9216959	01-10-92	AU-B- 655009	01-12-94
		AU-B- 1441292	21-10-92
		CA-A- 2106598	26-09-92
		EP-A- 0577667	12-01-94
		JP-T- 6508235	14-09-94
		US-A- 5433836	18-07-95
US-A-4851095	25-07-89	EP-A- 0328257	16-08-89
		EP-A- 0655515	31-05-95
		JP-A- 2004967	09-01-90
		US-A- 5124013	23-06-92
		US-A- 5225057	06-07-93
WO-A-9529272	02-11-95	US-A- 5480527	02-01-96
		AU-B- 2388795	16-11-95